

THE TEMPERATURE OF THE SUN

THE increase of the volume of atmospheric air, under constant pressure, being directly proportional to the increment of temperature, while the coefficient of expansion is 0.00203 for 1° of Fahrenheit, it will be seen that a temperature of 3,272,000° Fah. communicated to the terrestrial atmosphere would reduce its density to $\frac{1}{6643}$ of the existing density. Accordingly, if we assume that the height of our atmosphere is only 42 miles, the elevation of temperature mentioned would cause an expansion increasing its height to $6643 \times 42 = 279,006$ miles. This calculation, it should be observed, takes no cognizance of the diminution of the earth's attraction at great altitudes, which, if taken into account, would considerably increase the estimated height. Let us now suppose the atmosphere of the sun to be replaced by a medium similar to the terrestrial atmosphere raised to the temperature of 3,272,000°, and containing the same quantity of matter as the terrestrial atmosphere for corresponding area. Evidently the attraction of the sun's mass would under these conditions augment the density and weight of the supposed atmosphere nearly in the ratio of 279 : 1; hence its height would be reduced to $\frac{279,006}{279} = 1,000$ miles. But

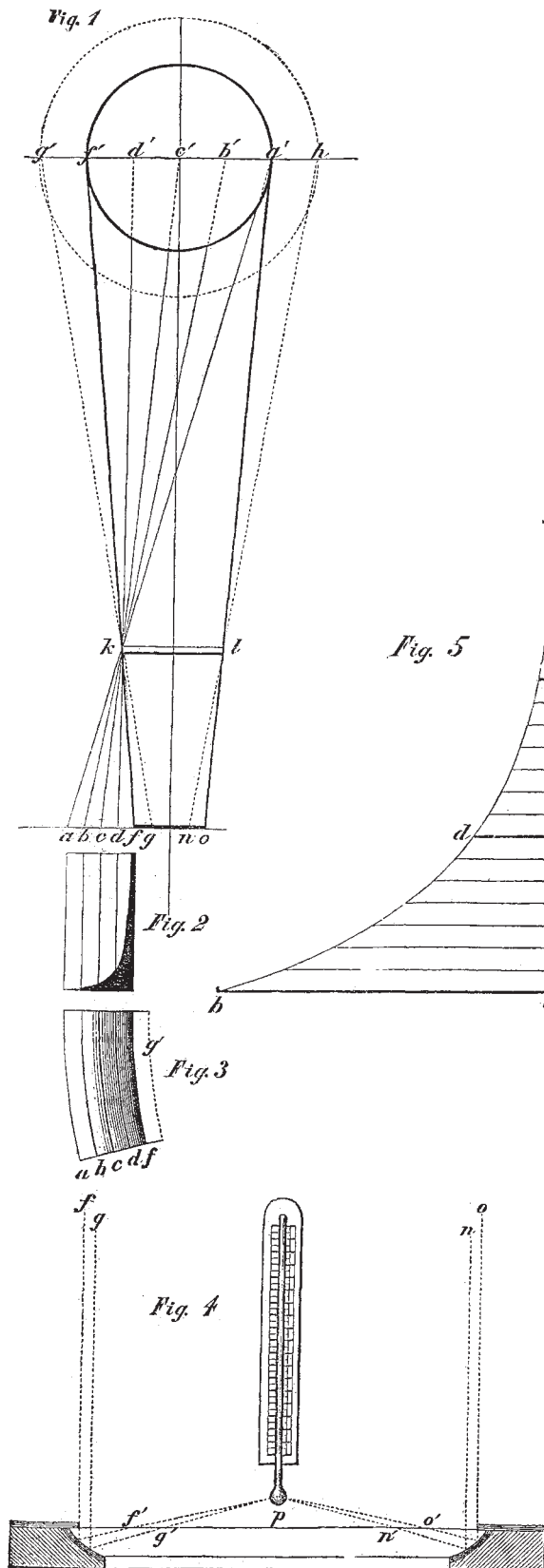
if the atmosphere thus increased in density by the sun's superior attraction consisted of a compound gas principally hydrogen, say 1.4 times heavier than pure hydrogen, the height would be $10 \times 10,000 = 100,000$ miles. The pressure exerted by this supposed atmosphere at the surface of the photosphere would obviously be $14.7 \times 279 = 410$ pounds per square inch, nearly. Unless, therefore, the depth greatly exceeds 100,000 miles, and unless it can be shown that the mean temperature is less than 3,272,000° Fah., the important conclusion must be accepted that the solar atmosphere contains so small a quantity of matter that notwithstanding the great depth it will offer only an insignificant resistance to the passage of the solar rays. Now, the assumed mean temperature, 3,272,000°, so far from being too high, will be found to be considerably underrated. It will be recollected that the temperature at the surface of the photosphere, determined by the ascertained intensity of solar radiation at the boundary of the earth's atmosphere, somewhat exceeds 4,035,000°. Consequently, as the diminution of intensity caused by the dispersion of the rays, will be inversely as the convex areas of the photosphere and the sphere formed by the boundary of the solar envelope, viz., 1.52 : 1, the temperature at the said boundary will be

$$\frac{4,035,000}{1.52} = 2,654,600^\circ$$

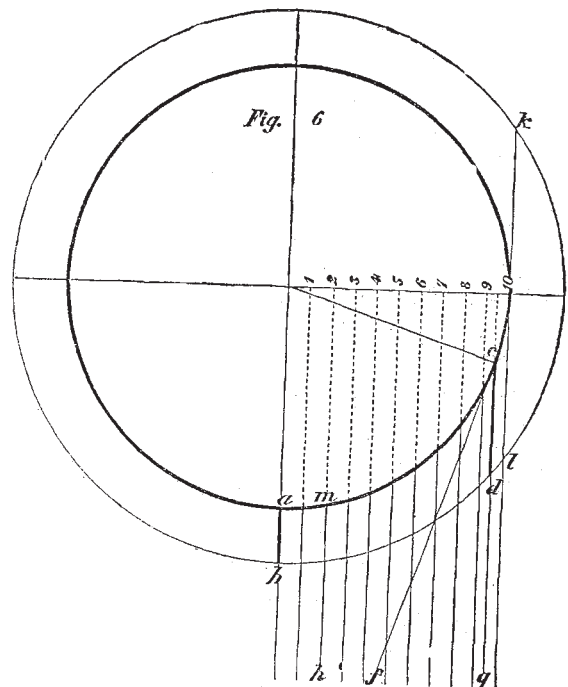
The true mean, therefore, will be 3,344,800°, instead of 3,272,000° Fah., a difference which leads irresistibly to the inference that, either the solar atmosphere is more than 100,000 miles in depth, or it contains less matter than the terrestrial atmosphere, for corresponding area. It will be demonstrated hereafter that the retardation of the rays projected from the border of the photosphere consequent on the increased depth of the solar atmosphere (supposed to be the main cause of the observed diminution of energy near the sun's limb), cannot appreciably diminish the intensity of the radiant heat. The ratio of diminution of the density of the gases composing the solar atmosphere at succeeding altitudes, is represented by Fig. 5, in which the length of the ordinates of the curve $a d b$ shows the degree of tenuity at definite points above the photosphere. This curve has been constructed agreeably to the theory that the densities at different altitudes, or what amounts to the same, the weight of the masses incumbent at succeeding points, decreases in geometrical progression as the height above the base increases in arithmetical progression. The vertical line $a c$ has been divided into 42 equal parts, in order to facilitate comparisons with the terrestrial

atmosphere, the relative density of which, at corresponding heights, is obviously as correctly represented by this diagram as that of the solar atmosphere. It is true that, owing to the greater height of the latter compared with the attractive force of the sun's mass, the upper strata of the terrestrial atmosphere will be relatively more powerfully attracted than the upper strata of the vastly deeper solar atmosphere. The ordinates of the curve $a d b$ will therefore not represent the density quite correctly in both cases. The discrepancy, however, resulting from the relatively inferior attraction of the sun's mass at the boundary of its atmosphere, will be very nearly neutralised by the increased density towards that boundary, consequent on the great reduction of temperature—fully 1,380,000° Fah.—caused by the dispersion of the solar rays before entering space. It may be well to add that, in representing the relative height and pressure of the terrestrial atmosphere, $a c$ in our diagram indicates forty-two miles, while $b c$ indicates a pressure of 14.7 pounds per square inch; and that in representing the solar atmosphere, $a c$ indicates 100,000 miles and $b c$ 410 pounds per square inch. Bearing in mind the high temperature and small specific gravity, the extreme tenuity in the higher regions of the solar atmosphere will be comprehended by mere inspection of our diagram. Already midway towards the assumed boundary, the density of the solar atmosphere is so far reduced that it contains only $\frac{1}{152,000}$ of the quantity of matter contained in an equal volume of atmosphere at the surface of the earth.

Let us now consider the diminution of intensity occasioned by the increased depth through which the heat rays pass which are projected from the receding surface of the photosphere. Fig. 6 represents the sun and its atmosphere extending $\frac{1}{2}$ of the semi-diameter of the photosphere, $m h$, $c g$, &c., &c., being the heat rays projected towards the earth. The depth of the solar atmosphere at a distance of $\frac{1}{2}$ of the radius from the centre of the luminary, will be seen to be only 2.0012 greater than the vertical depth. Now, careful actinometer observations enables us to demonstrate that when the zenith distance is under 60°, the radiant energy of the sun's rays in passing through the terrestrial atmosphere is very nearly in the inverse ratio of the cube root of the depth penetrated (see the previously published table). The increase of depth resulting from atmospheric refraction, it may be well to observe, is too small at moderate zenith distances to call for correction; nor does the atmospheric density vary sufficiently during bright sunshine to affect the radiant intensity appreciably. The table adverted to shows that an increase of the sun's zenith distance of 5' in 60° occasions a diminution of temperature hardly amounting to 0.044° Fah. Adopting the same rate of retardation for the solar atmosphere as that observed in the terrestrial atmosphere, it will be found that the loss of radiant energy of the solar rays at $\frac{1}{2}$ of the radius from the border of the photosphere will be only 1.26 greater than at its centre. According to the researches of Secchi and others, the loss is fully three times greater than that established by the rate of diminution which we have adopted. This circumstance, in connection with the extreme tenuity of the solar atmosphere, rendering any considerable loss improbable, points to the fact that some other agency than increased depth is the true cause of the diminution of the temperature under consideration. Accordingly, the writer some time ago instituted a series of experiments with incandescent cast-iron spheres, for the purpose of ascertaining practically if the reduction of temperature could be accounted for solely on the ground that the obliquity of the rays diminishes their energy. Previous experiments had demonstrated that the accepted doctrine is quite incorrect, which teaches that heat rays emanating from the surface of incandescent radiators are projected with equal energy in all directions. It was found during those



experiments that the ratio of diminution of radiant heat transmitted to a stationary thermometer by an incandescent circular disc of cast-iron, turning on appropriate journals, is directly proportional to the sines of the angles formed by the face of the disc and lines drawn to the centre of the bulb of the stationary thermometer. It was clearly shown that those heat rays only which are projected at right angles to the face of the incandescent radiator, transmit maximum energy. The important bearing of this fact with reference to temperature transmitted by the heat rays of the photosphere from points near the border, is self-evident. The small angle formed by the ray cg , Fig. 6, and the tangent cf of the surface of the photosphere at c , explains satisfactorily why the radiant heat at a distance of $\frac{1}{20}$ of the radius from the sun's border, is considerably less than at the centre. It will be perceived that the angle $fc d$ diminishes very rapidly as the border of the photosphere is approached, and that when the extreme point is reached, the radiant



$$ab = 1.0000 \quad cd = 2.0012$$

heat transmitted would be infinitesimal if the irregularity of the surface of the photosphere did not present a series of inclined planes capable of projecting heat rays in a direct line with kl .

Laplace, in the famous demonstration by which he proves that "if the sun were stripped of its atmosphere, it would appear twelve times as luminous" (*Mécanique céleste*, tom iv., pp. 284—288), commits the grave mistake of assuming that all rays emanating from a radiant surface possess equal energy. This assumption leads him further to the erroneous conclusion that the rays projected from the retreating surface of the sun near the limb, act as rays from a lens, being crowded together in consequence of the obliquity of the radiant surface, thereby, he supposes, acquiring increased intensity—hence the monstrous assertion of the great mathematician that, but for the interference of the solar atmosphere, the luminosity would be eleven times more intense.

The important question whether the solar atmosphere possesses any appreciable radiant power, and whether the

high temperature of the attenuated matter of which it is composed exercises any marked influence on the sun's radiant energy, may unquestionably be answered practically. An investigation, based on the expedient of concentrating the heat rays of the chromosphere by means of a parabolic reflector, has been conducted by the writer for some time. The method adopted is such that only the heat rays, if such there be, from the chromosphere and exterior solar envelope, are reflected; while the rays from the photosphere are effectually shut out. Fig. 1 shows the general arrangement; f' a' represents the photosphere, and g' h' the boundary of the surrounding atmosphere; $k'l$ is a circular screen exactly 10 inches in diameter, placed 53.76 inches above the base line ao . This distance obviously varies considerably with the seasons. Assuming that the investigation takes place when the sun subtends an angle of $32' 1''$, the screen $k'l$, if placed at the distance mentioned, will throw a shadow, fo , exactly 9.5 inches diameter; hence objects in the plane ao placed within fo , will be effectually shut out from the rays projected by the photosphere, while they will be fully exposed to the rays, if any, emanating from the chromosphere and outer strata of the solar envelope. It should be observed that, owing to diffraction in connection with the extreme feebleness of the sun's rays projected from the border, the shadow thrown by the screen $k'l$ extends considerably beyond the circular area defined by fo . Fig. 3 exhibits a full size segment of this shadow as it appears round fo , the section coloured black in Fig. 2 being a photometric representation of the strength of the said shadow from f to a . Special attention is called to this photometric representation, as it shows that objects placed within the circular area defined by fo are absolutely screened from the rays of the photosphere. It is evident that a parabolic reflector of proper size placed immediately below fo , will concentrate the radiant heat, if any, transmitted by the rays $f'f$ and $g'g$ and the intermediate rays. Fig. 4 represents a section of the parabolic reflector which has been employed during the investigation. It consists of a solid wrought-iron ring lined with silver on the inside, turned to exact form and highly polished. An annular plate 9.5 inches internal diameter, is secured to the top of the wrought iron ring to prevent effectually any rays from the photosphere reaching the reflector. The prolongation of the rays $f'f$ $g'g$ and $h'n$ $a'o$ are shown by dotted lines f_1g_1 and n_1o_1 ; also the reflected rays directed towards the bulb of the focal thermometer, marked respectively f_1o_1 and g_1n_1 . The investigation not being yet concluded, the following brief account is deemed sufficient at present. Turning the reflector towards the sun, without applying the screen $k'l$, a narrow zone of dazzling white light is produced on the black bulb of the focal thermometer, the mercurial column commencing to rise the moment the rays strike the reflecting surface. With a perfectly clear sky, the column during an experiment on August 29, 1871, reached 320° Fah. in thirty-five seconds. The screen $k'l$ being applied, after cooling the thermometer, a zone of feeble grey light appeared on the black bulb nearly as wide as the one produced by the rays from the photosphere, but situated somewhat lower. The column of the focal thermometer, however, remained stationary, excepting the oscillation which always takes place when a thermometer is subjected to the influence of the currents of air unavoidable in a place exposed to a powerful sun. It is proper to remark that owing to the stated oscillation, it cannot be positively asserted that there was no heating whatever produced by the reflection and concentration of the rays which formed the zone of grey light adverted to. But the recorded oscillations prove absolutely that the heating did not exceed 0.5° Fah. Assuming that such a temperature was actually produced by the reflected concentrated heat emanating from the solar envelope, the following calculation

will show that the energy thereby established is too insignificant to exercise any appreciable influence on the sun's radiant power. Theoretically, the temperature transmitted to the bulb of the focal thermometer by the rays f and o , Fig. 4, is inversely as the foreshortened illuminated area of the reflector to the zone of light produced on the bulb. Obviously these areas bear nearly the same relation to each other as the squares of f' or o' to the square of the radius of the bulb p . The length of f' being 4.77 in., while the radius of the bulb is 0.125 in.; calculation shows that the temperature transmitted by the ray f would be increased 1,456 times if the reflector did not absorb any heat. Allowing that 0.72 of the heat is reflected, the augmentation of intensity by concentration will amount to $0.72 \times 1,456 = 1,048$ times the temperature transmitted by the rays f and o . The records of the oscillations of the mercurial column during the experiments show, as stated, that the temperature resulting from concentration cannot exceed 0.5° , hence the temperature transmitted by the rays emanating from the heated matter

of the solar envelope will only amount to $\frac{1}{2 \times 1084} =$

0.00047° Fah. The observations having been made when the sun's zenith distance was $32^\circ 15'$, a correction for loss occasioned by retardation amounting to 0.26 will, however, be necessary. This correction being made, it will be found that the heat actually transmitted by the rays from the solar envelope during the experiment of August 29, did not exceed 0.00059° Fah., a fact which completely disposes of Secchi's remarkable assumption that the high temperature of the photosphere is owing to the "radiation received from all the transparent strata of the solar envelope" (see his letter to NATURE, published June 1, 1871). But we are not discussing the cause; the degree of temperature at the surface of the photosphere is the problem to be solved.

It was stated in the previous article that the radiant power of incandescent metals and metals coated with lamp-black and maintained at boiling heat, is directly proportional to the temperature of the radiator. A series of experiments with flames just concluded, proves positively that under similar conditions a given area of flame of uniform intensity transmits the same temperature as incandescent cast-iron. Secchi's assertion, therefore, that the photosphere, if composed of incandescent gases, "may have a very high temperature and yet radiate but very little," is wholly untenable. The diminution of intensity attending the passage of the heat rays from the photosphere through the surrounding atmosphere, is the only point which can materially affect the question of temperature. We have shown that on a given area, the quantity of matter contained in the solar atmosphere cannot greatly exceed that of the terrestrial atmosphere; hence the retardation cannot be great. True, the depth of the solar envelope is vast compared with that of the earth's atmosphere, but distance *per se* does not affect the propagation of radiant heat. Admitting, however, the retardation to be as the cube root of the depth—the ratio observed in the terrestrial atmosphere—it will be found that the loss of energy produced by retardation of the heat rays is not important. The solar atmosphere being $\frac{100,000}{42} = 2381$ times deeper than the

earth's atmosphere, the retardation caused by the former will be 13.3 times greater than that of the terrestrial atmosphere, which, as we know, diminishes the radiant intensity 17.64° on the ecliptic. Accordingly we are justified in asserting that $13.3 \times 17.64^\circ = 234.6^\circ$ Fah. will be the greatest possible diminution of temperature caused by the retarding influence of the matter composing the solar envelope. The admission in the previous article, that the retardation under consideration might be 0.01 , was based on the extreme assumption that the obstruction is directly

proportional to the depth of the sun's atmosphere. At first sight the loss of $234^{\circ}6'$ appears to be a trifling reduction of energy; yet if we consider the mechanical equivalent which it represents, we cannot doubt its adequacy to supply the motive force expended in producing the observed movement of the attenuated matter within the solar atmosphere. Dividing the temperature of the photosphere, $4,035,000^{\circ}$, by $234^{\circ}6'$, it will be found that the computed, apparently insignificant, retardation exceeds $\frac{1}{17,000}$ of the entire dynamic energy developed by the sun—an amount fully 15,500 times greater than the solar energy transmitted to all the planets of our system! Making due allowance for the extreme attenuation, and the small quantity of matter to be moved, the most exaggerated computation of the probable expenditure of mechanical energy called for in keeping up the currents of the solar atmosphere, fails to establish an amount at all equal to that capable of being generated by utilising 234° of the radiant heat emanating from the photosphere.

In view of the foregoing statements and the demonstrations contained in the previous article on solar heat, we cannot consistently refuse to accept the conclusion, that the temperature at the surface of the photosphere is very nearly $4,036,000^{\circ}$ Fah. J. ERICSSON

NOTES

THE Regius Professor of Physic at Cambridge (Dr. Bond) has issued a schedule of lectures on subjects connected with the study of medicine which will be delivered during the Academical year 1871-2. The following are the arrangements for this Term: Prof. Liveing will lecture on practical chemistry on Tuesdays, Thursdays, and Saturdays, at 1 P.M., commencing October 10. The Linacre lecturer will deliver a course of medical clinical lectures on Fridays, at 10 A.M., commencing October 13. The Professor of Anatomy (Dr. Humphry) will lecture on practical anatomy on Mondays, Wednesdays, and Fridays, at 6 P.M., commencing October 16. Mr. C. Lesturgeon, M.A., will on October 19 commence a course of surgical clinical lectures, and will continue the same on each Thursday during Term, at 11 A.M. Anatomy and Physiology will be the subject of a course by the Professor of Anatomy, commencing October 21, at 1 P.M., and continued on Tuesdays, Thursdays, and Saturdays at the same hour. The Professor of Zoology and Comparative Anatomy (Mr. A. Newton) will lecture on those subjects on Mondays, Wednesdays, and Fridays, at 1 P.M., commencing October 23. Special departments in chemistry will be the subject of lectures by the professor of that faculty on Tuesdays, Thursdays, and Saturdays at noon, commencing October 26. Practical histology will form a separate course under the superintendence of Dr. Humphry, commencing October 28 at 11.30 A.M., and continued each succeeding Saturday until its completion.

THE Franklin Institute of Philadelphia announces the following synopsis of lectures for 1871-72. The regular course will comprise a series of forty lectures, divided as follows:—1. "On Physics and Mechanics," by John G. Moore, M.S. 2. "On General Physics and Acoustics," by Prof. Edwin J. Houston. 3. "On Guns, Gunpowder, and Projectiles," by Lieut. C. E. Dutton. 4. "On the Chemistry of the Earth and of the Vital Process in Animals and Plants," by Prof. Samuel B. Howell, M.D. 5. "On the History of Alchemy," by William H. Wahl, Ph.D. 6. "On the Metallurgy of Iron and Steel," by Thos. M. Brown, Ph.D. Besides the lectures enumerated, the Institute has arranged with a number of eminent lecturers for the delivery of a popular course of scientific subjects, and it is believed that the plan here indicated, of offering a series of lectures brilliantly and largely illustrated, will go far towards attracting the attention and interest of the public to these most important subjects.

THE Managers of the London Institution, Finsbury Circus, announce the following programme of lecture arrangements for the coming season. The courses of educational lectures will be as follows:—First course, commencing Monday, October 30: Eight lectures "On Elementary Physiology," by Prof. Huxley. Second Course, commencing Monday, January 15, 1872: Eight Lectures "On Elementary Chemistry," by Prof. Odling. Third Course, commencing Monday, March 11, 1872: Six lectures "On Elementary Music," by Prof. Ella, director of the Musical Union. Fourth Course, commencing Monday, April 29, 1872: Six Lectures "On Elementary Botany; with special reference to the Classification of Plants," by Prof. Bentley. A Course of Four Lectures, adapted to a juvenile auditory, "On the Philosophy of Magic," by Mr. J. C. Brough, principal librarian in the London Institution, will be commenced on Thursday, December 21. A Course of Two Lectures "On Science and Commerce; illustrated by the Raw Materials of our Manufactures," by Mr. P. L. Simmonds, will be commenced on Thursday, November 23. This course will be illustrated by a large collection of beautiful and interesting specimens of animal and vegetable products. The following lectures will probably be delivered at the *Conversazioni* of the coming season:—"The Teachings of the Spectroscope," by Dr. William Huggins; "The Homing, or Carrier Pigeon: its Natural History, Training, and Exploits," by Mr. W. B. Tegetmeier; "The Sun," by Mr. J. Norman Lockyer; "Two Years' Gleanings in Syria and Palestine," by Captain Richard F. Burton; "The Haunts of Old Londoners," by Mr. Thomas Archer; "On Colour," by Prof. Barff. The evening class for elementary chemical analysis will commence work, under the direction of Prof. H. E. Armstrong, on Tuesday, November 7.

In his address at the recent opening of the new Mechanics' Institute at Bradford, Mr. W. E. Forster, M.P., remarked that when institutions of this kind were first established they were intended to give to mechanics scientific knowledge; but it was discovered that that was impossible, except in rare cases, because mechanics had no elementary teaching on which could be grounded scientific knowledge, and consequently these institutes were obliged to be turned very much into elementary schools and night schools, rather than into the teaching of science and higher literature, which we had hoped to give to our mechanics. A conviction, however, is now gaining ground that an essential portion of this elementary teaching consists of instruction in the rudiments of science, which would be of material advantage to none more than to the working classes.

THE open Scholarship in Natural Science, established this year at St. Mary's Hospital, has been gained by Mr. E. J. Edwards. This Scholarship is worth 40*l.* a year for three years. The Exhibition of 20*l.*, awarded at the same time, has been gained by Mr. Giles. Both gentlemen are students at the University of London.

THE Ettles Scholarship at the University of Edinburgh, which is annually awarded to the most distinguished graduate, has been given to Dr. Urban Pritchard, a student of King's College, London. Dr. Pritchard also gained a gold medal for original researches on the structure of the organ of Corti, conducted by him in the physiological laboratory of King's College.

THE vacancy in the Botanical Department of the British Museum, caused by the promotion of Mr. Carruthers, has been filled by the appointment of Mr. James Britten, late assistant in the Royal Herbarium, Kew.

MR. ROBERT ROUTLEDGE, a scientific graduate in honours of the University of London, has been appointed conductor of the classes in Chemistry and Physical Science at the Manchester Mechanics' Institute. These classes are intended to encourage technical education among the working classes, and consist of